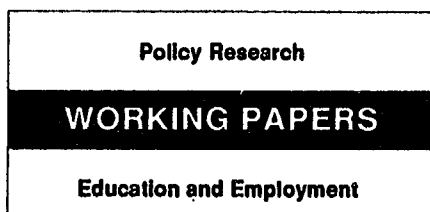


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Education, Externalities, Fertility, and Economic Growth

Martin Weale

Education yields externalities that appear stronger in macroeconomic data than in household-level studies. Simulations show that there is a small growth externality as well as a fertility externality which is influenced by the rate of return to education relative to that on physical capital.

This paper — a product of the Education and Employment Division, Population and Human Resources Department — is part of a larger effort in the department to establish the linkages between human capital investments and economic development. Copies of the paper are available free from the World Bank, 1818 H Street NW, Washington DC 20433. Please contact PHREE, room S6-214, extension 33680 (November 1992, 51 pages).

The benefits of education are usually assessed by analyzing rates of return. Social rates of return reflect the fact that education may be provided free or at a subsidized price and that a part of any individual's income accrues to the state through taxation. But they typically do not include private benefits that are not directly connected with the individual's gross earnings; nor do they include the external effects of education on economic growth.

Some benefits are generally omitted from calculations of social returns to education, but the estimates produced — ranging from 13 percent to 26 percent — are implausibly high. There are several reasons for this. Studies may not reflect the fact that family background influences both the likelihood of participating in education and a person's future earning power even without education. Failure to take account of the effects of quality of education may also lead to upward bias.

An alternative approach is to make cross-country comparisons using macroeconomic data. A number of such studies are discussed. In assessing whether education has any external effect on economic growth, assumptions must be made about education's direct effect on earning

power. Based on a conservative figure of a 5 to 8 percent increase in earnings for every year of education, there is some evidence to support the presence of a small externality, but the evidence cannot be said to be overwhelming.

There is, however, much clearer evidence of a link between education and fertility rates. The effect is observed in both macroeconomic data and household studies, but is stronger in macroeconomic data for reasons that are not clear. This effect constitutes an externality that — at a time of widespread (but not universal) concern about population growth — is of great importance.

Weale develops a simulation model from work by Barro and Becker. The model links fertility decisions with consumption/saving decisions. In this model, parents derive utility from their children's welfare; as a consequence, children are a form of saving. The model is extended to reflect education as an endogenous decision and then further to look at the effects of an external effect of education on economic growth. Simulations demonstrate that the rate of return on education relative to that on physical capital is a major influence on fertility, suggesting that the model sheds some light on education's external effect on fertility.

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EDUCATION, EXTERNALITIES, FERTILITY AND ECONOMIC GROWTH

Martin Weale

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1. Introduction

Analysis of the economic effects of education has usually focused on an assessment of the rate of return. A comparison of the incomes of the educated with those of the uneducated allows a rate of return to education to be calculated. In addition to this private return to the individual, a social rate of return can also be estimated, taking into account the cost of education to society rather than on individual's incomes. To the individual, education incurs a direct cost in terms of fees and an additional opportunity cost in terms of earnings foregone. The social cost of education is likely to differ from the private cost because many countries have a policy of providing at least basic education free or at a heavily-subsidized price. The social return also differs from private return because individuals receive their incomes net of taxes, while the contribution to national income is made gross of tax. Estimates of the private and social return to education are presented in section 2.1

There are a number of reasons for being unhappy with an approach based on the rate of return as it is usually calculated. These are also discussed in section 2.1. First of all, in the nature of things, one cannot identify all the factors which influence earning power. Individuals with a favorable family background may be more likely to receive education, and the effects of family background may be mistaken for the effects of education. Secondly, the specific inclusion of variables reflecting the quality of education may influence assessments of the rate of return. Thirdly, education may confer a relative advantage as much as an absolute advantage. It may allow the educated to gain at the expense of the uneducated. On the other hand, analyses based on macroeconomic data, such as those of section 2.2, should not be susceptible to this problem.

These macroeconomic studies typically explain economic growth over a period of twenty years or more by means of investment in physical capital, variables representing education level, or, in one study, expenditure on education, and variables summarizing political instability. They provide a basis for assessing the argument that education may have effects on economic performance over and above those identified by the usual rate of return analysis. Education may facilitate technical progress. This will benefit both the educated and the uneducated alike. This, if true, creates an externality which is likely to be reflected in any analysis based on macroeconomic data but will obviously not be visible in any cross-section study. This part of the paper looks at the evidence for an external effect of education on growth.

There may be other benefits of education. There is good evidence, presented in section 2.3, to suggest that education reduces fertility rates. If one is persuaded that high fertility poses a major long-term threat to living standards, then this externality may be of very great importance, particularly since the evidence for this externality is stronger than for an externality linking education to economic growth. On the other hand, it is not obvious what economic value should be placed on the fertility rate; in this paper, no valuation is attempted in the assessment of this effect.

At the same time as reducing fertility, and possibly partly related to this, education seems to have a positive influence on health. In section 2.4, a variety of effects are discussed. In developing countries parental education leads to a reduction in child mortality. Related to this, despite not being an external effect, is the suggestion that healthy children learn more efficiently.

While the effects of improved health are very important, they are also reasonably straightforward to appreciate. The theoretical basis for the impact of education on fertility and economic growth, however, merits further investigation. In section 3, a simulation model is developed. This model assumes that family size is an economic choice and sets out, first of all, the links between education and fertility, on the assumption that technical progress is exogenous. It is demonstrated that fertility increase is decreasing in the cost of raising children, but increasing in the rate of exogenous *per capita* growth. Education is introduced into the model by making the duration of education (and thus the cost of raising children) sensitive to the return to education. The interaction between the return to education and the endogenously-determined return to physical capital appears to be the dominant route by which the return to education influences fertility.

In section 4, the model is extended by making technical progress depend on the duration of education; the simulation results enable one to identify the overall effects of an extension of education in terms of population growth and technical progress, as well as reflecting the effects which enter into conventional rate of return calculations. These simulations show a link between fertility and growth reasonably similar in magnitude to that identified in empirical studies.

There is good reason to believe that the demand for education is sensitive to economic factors. Several studies (for example, (King and Lillard (1987))) look at the effects of the cost of education and confirm that demand is sensitive to its price. They also stress the importance of accessibility as a factor influencing the take-up of education. But the external effects alluded to above mean that one cannot rely solely on market forces to deliver a socially desirable amount of education.

2. Economic Development and Education: Some of the Issues Involved

There are several important routes by which education can influence an economy. First and foremost, education raises labor productivity. Improvements in the educational attainment of the population will tend to be associated with economic growth. This may be enhanced by the externalities discussed above. An individual may be more likely to benefit from a given level of education if there are others with whom to co-operate. And a high flow of investment in education is likely to lead to more rapid growth in knowledge and thus to faster technical progress. Secondly,

there are a number of other effects. The most important of these is the effect of education on fertility, with educated populations growing more slowly. Productivity is also improved in the household sphere. Educated farmers are more productive. And a higher level of education is associated with a higher standard of health. These effects may then feed back into productivity. A more healthy workforce is more productive. And lower fertility is likely to lead to more healthy children who may learn more at school and be more healthy and more productive as adults.

In the context of developing countries, education is also an important policy vehicle for tackling poverty through stimulating economic growth. The 1980 *World Development Report* emphasized how important education is in terms of influencing economic growth. In particular it was stressed how human development, a condition directly and indirectly affected by education, can lead to reductions in absolute poverty by promoting growth. Psacharopoulos and Steier (1988) observed this process in Venezuela between 1975 and 1984. Human development encompasses education and training, improvements in health and nutrition, and reductions in fertility rates. This view was reiterated in the *World Development Report*, 1990 which stated

"...there is ample evidence that investing in human capital, especially education, also attacks some of the most important causes of poverty."

Streeten (1981) argues that the externalities derived from basic education can be large in developing countries, providing ample justification for expanding resources on primary education. We now proceed to explore the economic consequences of education and its external effects in greater detail.

2.1 Human Capital and the Return to Education in Developing Economies

The Human Capital hypothesis was proposed by Schultz (1963) and Becker (1964) and has been one of the most influential in the area of the economics of education. It postulates that an individual chooses an amount of time to devote to education, based on the expected return and expected cost. This approach is concerned primarily with choice in education and is less relevant to compulsory education¹. An individual incurs two types of cost when in education. First, there are the direct costs, such as books, tuition fees, etc., and secondly there are foregone earnings. Human capital models view educational choice as an investment with individuals being concerned about rates of return. If an individual's private rate of return for some level of education X exceeds the rate of interest, then it is sensible for the individual to be educated at least to level X. One problem in the context of developing economies is that imperfect capital markets and low

¹Although in many countries compulsory education is not enforced, particularly in rural areas where monitoring is difficult.

levels of educational provision may make it difficult for individuals to fulfil optimal plans. Individuals may be unable to implement their best strategies.

The preceding discussion summarizes the basis of individuals' private calculations. The social return does not necessarily coincide with the private return and, from the perspective of the state it is the social return which matters. The social rate of return of increasing educational expenditures is based on pre-tax salaries and costs borne by society as a whole (foregone output opportunities, resource costs of education, etc.). It is usually found for advanced economies that the private return exceeds the social return (Ziderman, 1973, Morris and Ziderman, 1971). These calculations, which are made by a comparison of the incomes of the educated with those of the uneducated, omit any externality effects which might be significant within the context of developing and developed economies. They do not reflect the fact that primary education may lead to more efficient use of expenditure on public health, or that education at more advanced levels may increase the rate at which developing countries can take technical advances on board.

A separate problem arises as far as the calculations of private rates of return are concerned. These represent the average return, but, for any individual, there is a substantial margin of uncertainty over the benefits of education. In consequence the average return will have to include a premium over the return on 'safe' assets before risk-averse individuals can be persuaded to invest in education (Levhari and Weiss, 1974).

The greatest direct return derived from education in developing economies for which the evidence can be described as unambiguous is the improvement to labor productivity. These lead individuals to attain higher incomes which is reflected in studies that have focused on rates of return.² Psacharopoulos (1985) surveys a large number of such studies (see table 1) and finds high rates of return to education in developing countries. For example, the average social return to education in sub-Saharan Africa ranges from 26% for primary education to 13% for higher education; for Asia the figures are 27% and 13%, respectively, for Latin America and the Caribbean 26% and 16%, respectively, with the private return tending to be higher still.

World Development Report, 1991 (p. 57) quotes the results of recent studies suggesting that an incremental year of education raises wages by between 5% and 25%. These figures are complimented (p. 43) by estimates for the effect of extension of education on the level

²The majority of research on the link between education and productivity is conducted by looking at returns based on income streams. This is very much within the framework of the human capital approach. Within the context of the U.S. Horowitz and Sherman (1980) have undertaken a study of the direct effects of human capital on productivity. This study was conducted on the U.S. Navy.

of GDP which imply a much lower return to education. One extra year of education of the workforce will, it is suggested, raise GDP by 9% for the first three years of education, falling to 4% for further years of schooling. If the social return calculated from earnings data is 20% and the share of labor in the national product is 75%, then an extra year of education for the whole workforce should raise GDP by around 15%³. If the figure of 4-9% is believed to be consistent with the microeconomic results, it implies that the main benefit of education is simply to give people an advantage in a close to zero sum game. But it is, on balance, unlikely that the main effect of education is to allow the educated to gain at the expense of the uneducated; more probably the high survey-based estimates of social rates of return should be treated with caution. There are a number of reasons for this.

Table 1 **Selected Studies of the Return to Education**
Calculated from Survey Data

Behrman and Birdsall (1983)	Rates of return in Brazil. 6171 males from 1970 Census.	Study takes account of quality as well of education.
Psacharopoulos (1985)	Survey of rates of return	Summary of 105 country studies. 55 were developing countries. The estimates are calculated from cross-section data. Private and social rates of return shown. Social rates of return do not include any external effects.
Glewwe (1991)	Rates of return in Ghana 3200 households in 1988-89 survey. Results on 1586 households used in this study.	Study assesses return to schooling separately to literacy and numeracy.

First of all, there is the possibility that, when estimates of the return are based on cross-sectional analyses, then the estimates are likely to reflect in part high scarcity returns to a few more educated individuals. According to Behrman (1990) this is unlikely to persist over time. This

³The calculation is not exact because, if the social rate of return to education is 20%, the effect on adult wages of an extra year of education will differ slightly. It will be higher because the cost of providing the education is reflected in the social cost, but lower because child wages may be below adult wages. Not too much weight should be placed on the second point because, in developing countries, people in their mid to late teens are often found in primary schools.

in itself need not be a source for great concern. Psacharopoulos (1985) shows social rates of return of around 10% even in the advanced countries.

Of greater concern is the suggestion that the cross-section studies contain many flaws leading to an upwards bias in the estimates (Behrman and Birdsall, 1987 and Behrman, 1990)⁴. Two studies in particular have attempted to correct for this bias. One important source of bias omitted from most studies is a measure of the quality of schooling (see also below). Behrman and Birdsall (1983,1985) explored this issue for a sample of males in Brazil. The sample studied exhibits a private rate of return of 20.5%, but adjusting for quality (proxied by length of schooling for teachers), the rate dropped to 11.0%. (The work of Card and Krueger (1992) discussed below also shows that the return to education is positively correlated with schooling quality.)

A recent study by Glewwe (1991) using data from Ghana has also tried to overcome problems of bias in estimating the return to education. This work takes account of variation in cognitive ability and in school quality⁵. He shows that, with the omission of variables that are positively correlated with years of schooling, such as school quality and family background, ordinary least squares estimators will be biased. His research is very critical of the estimation of rates of return to additional years of schooling. Despite the concerns over his data voiced in footnote 5 below, there can be little quarrel with his argument that the return arises to skills and not to schooling *per se*. He concludes that the private rate of return to education in Ghana is at most around 6% p.a. and suggests that "rates of return to improvements in school quality" are needed. An implication of his finding is that other studies of rates of return may provide misleading policy recommendations about educational investment programs.

There have been a number of other studies looking at the effects of education quality, although most of these have been carried out in the United States. In 1966 the influential

⁴Bennet, Glennester and Nevison (1992) come to a similar conclusion for higher education in the United Kingdom. Their argument is that higher education is disproportionately taken up by people whose background would, in any case, tend to give them access to better-paid jobs.

⁵One concern about the data used in Glewwe's study is that they show the average duration of schooling to be 9.59 years. This compares with OECD figures for 1974 showing lower figures in Denmark, France, Germany, Greece, Italy, the Netherlands, Norway, Portugal, Spain and Sweden. Only Belgium, Canada, UK and USA show longer schooling duration. Nevertheless *World Development Report, 1991* shows 40% of the population and 57% of the female population as illiterate. Even in 1988 only 73% of the relevant age group were enrolled for primary education, with only 39% enrolled for secondary education. It would be interesting to know whether the survey results have been cross-checked with aggregate data on school attendance. Obviously any inflation of the number of years of education claimed by the respondents will tend to depress the estimated return. Literacy and numeracy, if measured as part of the survey are much less likely to be exaggerated.

Coleman Report found little association between the quality of schools and student achievement on standardized tests.⁶ Recent research by Card and Krueger (1992) indicates, however, that a large part of the significant variation in the rate of return to education in the U.S. is explained by differences in the quality of schooling. For example, the return is higher for individuals who attended schools with lower pupil/teacher ratios and with higher relative teacher salaries. They also find that the return is linked to higher education among teachers.

An important policy issue in development economies arises in the context of the length of compulsory schooling. Angrist and Krueger (1991) have undertaken some work on this in the context of the U.S. Their results point in the direction of compulsory schooling laws leading to increases in educational attainment. They do not, however, answer the question: do compulsory schooling laws benefit society? They suggest an answer to this question requires research into the social and private costs of education.

Whether omitted variables disrupt rate of return calculations or not, there is the separate problem that they do not allow the identification of external effects on economic performance. We therefore now turn to macroeconomic studies which should, in principle, show any such effects.

2.2 *Macroeconomic Evidence for Links between Education and Economic Growth*

The approach summarized by Psacharopoulos (1985) has the drawback that it fails to reflect all externalities arising from higher education and, conversely that it is susceptible to the biases mentioned above. An alternative means of identifying the effects of education is to use a regression equation to explain cross-country differences in economic growth, or variations in growth rates in the same country in different periods.

Behrman (1987) finds a negative but insignificant correlation between the change in literacy and economic growth and Dasgupta and Weale (1992) come to a similar conclusion. But it is questionable whether literacy, even if a good indicator of educational attainment, is measured reliably and this, on its own, should not be taken as evidence against a positive link between education and economic performance.

Table 2 summarizes some studies which use macroeconomic data; regression results linking economic growth to education and to other variables are presented in table 3. McMahon (1987) claims to find a return of the order of 20% for investment in education in Africa. This

⁶A survey of the literature can be found in Hanushek (1986).

estimate is calculated from macroeconomic data, assessing the growth in real GDP attributable to investment in physical and human capital. There are a number of problems with his study. His method (table 3i) shows a negative return to higher education. If a longer lag is put on higher education, then the term in primary/secondary education loses its significance. He calculates the return to primary and secondary education from the first regression in table 3i and the return to higher education from the second regression, adding the current and lagged terms on higher education together. This is somewhat lacking in coherence. Thus his claim that his method shows a return very similar to the figures presented by Psacharopoulos for Africa should be regarded with skepticism. If his claim were true, it would imply that there is no benefit from education except that reflected in those earnings differentials which are used to calculate the figures surveyed by Psacharopoulos (1985), or that the external benefits offset the biases referred to above.

The main virtue of McMahon's study is that he attempts to measure investment in human capital by means of expenditure on education (including earnings foregone), and this allows him to interpret his regression coefficients as rates of return. However, these expenditure data must be subject to a large margin of error, and this probably explains why, in the other studies in tables 2 and 3, enrolment data were used instead.

Baumol, Blackman and Wolff (1989) find growth in real GDP/GNP *per capita* to be positively influenced by education at all levels. They explain the growth in *per capita* GDP/GNP by a catch-up effect (expressed by the use of initial GDP/GNP), the rate of population growth and the fraction of the appropriate age group enrolled in primary or secondary school or in higher education in 1965.

Five regressions are presented, using different measures of GDP/GNP over slightly different periods, but only one, looking at real GNP in constant price dollars begins in 1965 and so avoids the risk of simultaneity bias with the education data; this is presented in table 3ii. An increase of 10% in the fraction at primary school raises the level *per capita* GNP in 1984 by 4.2% for a given value of 1965 *per capita* GNP. This suggests an effect on the growth rate of 0.21% p.a. Secondary education is found to be twice as good, with a figure of 9.1% over 20 years or 0.46% p.a. Tertiary education is even better. The figure is 11.3% over 20 years or 0.57% p.a. These are the results of three separate regressions: in those for secondary and higher education the population growth variables are not significant, although they become so with measures of GDP based on purchasing power parity.

Table 2 Studies of the Return to Education Calculated from Macroeconomic Data

McMahon (1987)	Regression on Growth in GDP per person employed	Increase in GDP per person employed explained by inputs of labor and capital and expenditure on primary and secondary education (taken together) and higher education.
Baumol, Blackman and Wolf. (1989)	Regression on Growth in GDP <i>per capita</i>	Growth in output of 103 countries 1960- 85 <i>per capita</i> explained by initial GDP <i>per capita</i> and enrolment rates in primary, secondary and tertiary education. GDP evaluated at international prices.
Barro (1991).	Regression on Growth in GDP <i>per capita</i>	Growth in output of 98 countries 1960- 85 <i>per capita</i> explained by initial GDP <i>per capita</i> , enrolment rates in primary and secondary school, the share of government consumption in GDP, the investment ratio, measures of political and social instability, price distortion and fertility. Fertility rates are also explained
<i>World Bank Development Report, 1991</i>	Regression on Growth in GDP	Growth in GDP of 68 economies the period 1960-87 explained by means of increases in capital, labor and agricultural land, and level and change in educational attainment.
Mankiw, Romer and Weil (1992)	Regression on Growth in GDP per working-age person	Growth in output of 75 developing countries 1960-85 explained by average investment ratio and average fraction of working-age population at secondary school.

Table 3

Regressions Explaining Economic Growth

i) McMahon. (1987, p. 189)

Regression equation for 30 African Countries

	$\Delta N/N$	I/Y	I_H/Y	I_{HD}/Y	I_{HD}/Y_{-1}	R^2
$\Delta Y/Y - \Delta N/N$	-0.35 (0.8)	0.65 (3.1)	1.62 (2.2)	-5.02 (1.5)		Not given
$\Delta Y/Y - \Delta N/N$	-0.84 (2.4)	0.31 (1.3)	0.92 (0.5)	-4.08 (1.1)	7.15 (2.0)	Not given

 $\Delta Y/Y - \Delta N/N$ Growth in labor productivity for 30 African countries over the five-year periods 1970-75, 1975-80 and 1980-85. I/Y Investment ratio for each country in the first year of each five-year period. I_H/Y Investment in education as fraction of GDP in the first year of each 5-year period. I_{HD}/Y Investment in higher education as fraction of GDP in the first year of each 5-year period.

The subscript -1 indicates a lag of 5 years.

The regression included as other explanatory variables initial productivity, changes in utilization of capital rates, dummies for oil exporters, oil and drought shocks, language (english or french) and a lagged dependent variable.

ii) Baumol, Blackmann and Wolff (1989)

Regression equations explaining the ratio of 1981 to 1960 real GDP *per capita* measured at 1975 international prices

Constant	Initial RGDP	Primary	Secondary	Tertiary	R^2	Sample Size
-0.081 (0.9)	-0.599 (1.6)	0.791 (5.8)			0.273	103
0.318 (5.7)	-1.678 (2.9)		1.386 (4.7)		0.227	103
0.375 (6.3)	-0.627 (1.1)			2.703 (2.7)	0.094	103

Initial RGDP GDP *per capita* in 1960

primary primary school enrolment rate in 1965

secondary secondary school enrolment rate in 1965

tertiary higher education enrolment rate in 1965

iii) Barro (1991, p. 429)

Regression equations explaining growth in real GDP *per capita* 1960-85 at an annual rate and fertility rate net of child deaths up to the age of 4.

Cons	GDP 60	Primary	Secondary	g^*/y	REV	ASS	PPI DEV	i/y	FERT-NET	R^2
0.022 9 (3.2)	-0.0072 (8.0)	0.0181 (3.0)	0.0225 (2.5)	-0.119 (4.4)	-0.0159 (2.6)	-0.0315 (1.7)	-0.0119 (2.1)	0.068 (2.1)		0.59
0.049 4 (4.1)	-0.0077 (8.6)	0.0118 (2.0)	0.0100 (1.1)	-0.114 (4.4)	-0.0167 (2.6)	-0.0254 (1.5)	-0.0103 (1.7)	0.064 (2.0)	-0.0043 (3.1)	0.62

There are 98 observations in each regression

GROWTH growth in *per capita* GDP between 1960 and 1985 at 1985 prices at an annual rateGDP60 GDP *per capita* in 1960 at international prices

Primary primary school enrolment rate in 1960

Secondary secondary school enrolment rate in 1960

 g^*/y average ratio of government consumption (excluding defence and education) to GDP, 1970-85

REV average number of revolutions and coups per year, 1960-85.

ASS Number of assassinations per million population per year, 1960-85

PPIDEV Deviation of price of investment goods from sample mean in 1960

 i/y Average ratio of domestic investment to GDP, 1960-85

FERTNET No of children per woman surviving beyond the age of 4. Average of 1960-85.

iv) *World Bank Development Report, 1991, p. 159.*

Regression equation explains growth in GDP over the period 1960-89.

ZK	ZL	ZH	DE03	DE39	E60	R ²
0.38 (17.7)	0.44 (3.6)	0.04 (1.3)	0.09 (2.5)	0.04 (1.9)	13 (1.5)	0.23

ZK change in log of utilized capital, 1960-87

ZH change in log agricultural land, 1960-87

ZL change in labor force, 1960-87

DE03 increase in average annual years of education if level ranges from 0 to 3

DE39 increase in average annual years of education if level ranges from 3 to 9

E60 average number of years of education of population aged 15-64 in 1960

v) Mankiw, Romer and Weil (1992, p. 429)

Regression equation explains growth in real GDP per person of working age 1960-85

Constant	ln Y60	ln(I/GDP)	ln(n+g+d)	ln (School)	R ²
3.09 (5.8)	-0.372 (5.6)	0.506 (5.3)	-0.772 (**)	0.266 (3.3)	0.44

There are 75 developing countries in the regression equation.

Y60 GDP per person of working age in 1960

I/GDP average ratio of investment to GDP, 1960-85

n+g+d population growth rate plus technical progress and depreciation rates (the latter two are assumed to add to 0.05)

School fraction of 12-17 year olds attending secondary school multiplied by fraction of working-age population aged 15-19

The regression is restricted so that the coefficients on the investment ratio, SCHOOL and on the sum of growth of working-age population, growth and depreciation add to zero. The restriction is accepted at a 42% confidence level.

It is difficult to interpret the results. Baumol, Blackmann and Wolff suggest that higher education makes less of a contribution to economic growth than does secondary education simply because the significance level associated with the variable is lower. They do not discuss the fact that the coefficient itself is higher. The most natural way to compare the effects of the three types of education would be to place all three variables in a single regression equation. This would allow one to test and perhaps then impose the hypothesis that all three types of education have the same effect on growth. One cannot, from their results, anticipate the outcome of this test.

The second study is provided by Barro (1991). He presents a number of regression explaining growth in GDP *per capita* of a wide range of countries by a number of variables describing education and political and social stability. The equation in table 3iii suggests that an increase of 10% points in the fraction of the school-age population attending secondary school raises the *per capita* growth rate of GDP by 0.2% p.a. A similar increase in the growth rate is achieved by a 10% point increase in the fraction of the school-age population attending primary

school, so that a 10% point increase in the fraction of the age group processed by both school systems will add 0.4% p.a. to the *per capita* growth rates.

However the inclusion of two types of extra factors reduces the apparent effect of education. The inclusion of fertility as an explanatory variable halves the influence of both types of education and leaves them statistically insignificant. One should not worry too much about this. It is subsequently argued that fertility is likely to be a function of education, and indeed one of Barro's regressions shown in table 5 suggests that this is indeed the case. An implication of this is that the equation including the effects of fertility suffers from simultaneous equation bias, and the reduced form which excludes it is to be preferred.

The introduction of dummy variables for Africa and Latin America in addition to fertility has the effect of reducing the coefficient on secondary education to close to zero (0.04% growth for 10% increase in the share of the population at secondary education) but raising the coefficient on primary education to 0.15% p.a. for a 10% point increase in the share of the age group at primary school. Once again it may be that, if the coefficients were restricted to be equal, a significant term would be found. One might conjecture that the total direct effect of education on growth would be of the order of 0.2% p.a. per 10% increase in the population, but if the endogenous effects of fertility changes are taken into account then the figure of around 0.4% p.a. may become more relevant.

The role played by the dummy variables for Latin America and Africa is not clear. One interpretation consistent with the model is that the quality of education there is worse than elsewhere, and one way of correcting for this would be to look at expenditure on education rather than participation rates as explanatory variables. On the other hand, of course, the Latin America/Africa effect may be quite independent of schooling and omission of the dummy variable simply biases upward the education variables.

World Development Report, 1991 presents a regression which explains growth in output by means of growth in inputs and by the initial level of education of the workforce, and the increase in educational attainment of the workforce in the period under study. In fact five regressions are presented. Some of these include variables representing the effects of price distortions, but the inclusion of these variables does not have much effect on the coefficients estimated for the variables shown in table 3iv), and these are therefore taken from the regression without the effects of price distortions. The regression investigates whether expansion of 0 to 3 level education has effects different from those of 3 to 9 level education. Although a higher coefficient is found on 0 to 3 level education, it is not significantly higher. The initial level of education is not

statistically significant, although, converting to an annual growth rate, it does appear, dividing the estimated coefficient of 13 by the 27 years of the period, that one extra year of education in 1960 raises the growth rate of a developing country by 0.48% p.a. over the period 1960-87. This term can be regarded as representing a pure externality effect, with a higher level of education raising the rate at which technical progress is possible. It compares with a statistically significant figure of 0.14% p.a. found by Weale (1992) for the developed countries. The coefficients on increased availability of education have no counterpart in Barro's study. Nevertheless, the *World Development Report* study suffers from the presence of a number of poorly determined coefficients, and the imposition of some theoretical restrictions, similar to those applied to the study discussed next, would help in the interpretation of the results.

Mankiw, Romer and Weil (1992) present the results of an exercise similar to those of Baumol and *World Development Report*, 1991, but with fewer explanatory variables, and using what is probably a less satisfactory measure of educational attainment. They explain the increase in output per person of working age between 1960 and 1985 by means of 1960 output per person of working age, the average investment ratio, the increase in population and the average fraction of the workforce attending secondary school (SCHOOL), with all variables being expressed in logarithms. Dividing their coefficients by 25 to convert them to explain growth at an annual rate, the coefficient on SCHOOL falls to 0.011 and that on the log investment rate to 0.020. However one must also divide Mankiw, Romer and Weil's coefficients by the sample means in order to make them comparable with those figures estimated in levels rather than logs. With an average of around 20% of the product invested, Mankiw, Romer and Weil's coefficient on investment would be comparable to a figure of 0.1 in Barro's equation.

It is still not possible to make a direct comparison of the education effects because Mankiw, Romer and Weil look at the fraction of the working-age population attending secondary school and not at the fraction of the school-age population attending secondary school. However, if we assume that 38% of the relevant age group attended secondary school over the period (being the mean of the 1960 and 1985 figures quoted by Barro), then the coefficient of 0.011 must be divided by 0.38 to make it comparable with Barro's. The resulting figure, of 0.027 is higher than Barro's estimate of 0.018, but it must be remembered that Mankiw, Romer and Weil omit any effect from expansion of primary education. If expansion of primary education is correlated with that of secondary education, then their regression would be expected to overstate the effects of secondary education. One might also be concerned that they use average school attendance during the sample period, and there is a risk of simultaneity bias arising from interaction between this and output growth. Furthermore, the analysis of section 4 implies that there is also a risk of simultaneity between education and population growth, suggests the desirability of using instrumental variables.

As was also noted in the discussion of Barro's results, without this one cannot be confident that the regression provides a satisfactory estimate of the effect of education on growth.

Nevertheless, an important aspect of Mankiw, Romer and Weil's results is that the restriction which they test and impose, that the coefficients of the investment ratio, SCHOOL and the sum of population growth, technical progress and depreciation add to zero, has the implication that there are no spatial externalities linking education to economic growth. This is discussed further in section 4.

It has been argued that the *World Development Report, 1991* regression is inconclusive as to whether there is an externality present or not, but one should also ask whether of Barro's figures, which include both primary and secondary education in the regression, suggest an externality. His figures can be compared with the results found by Weale (1992) in the developed world. In this study an increase of one year in the average number of years of education of the workforce raised the rate of growth of *per capita* GDP by 0.14%. Since the average number of years of education of the workforce in the sample of countries considered was just over 9, this is equivalent to an increase of 11% in the fraction of the population attending a 10-year schooling program. Alternatively, a 10% increase in secondary-school throughput would be associated with an increase in the growth rate of 0.127% p.a.

If one assumes that fertility effects are of no great importance in the developed world, Weale's figure appears to be below Barro's estimate of 0.23% p.a. But the nature of the effects identified by Barro merits some discussion. In fact his figures represent two effects, a stock effect and a flow effect. It is clear from his data that school enrollments have been rising during the period of his sample. As the number of educated people rises, so will the level of output. Denison (1967) suggests a rule of thumb that one extra year of education adds 5% to labor productivity up to the eighth year of education. Beyond that, one extra year adds 8% to productivity. Barro's data indicate a sharp increase in the fraction of the school-age group enrolled at school between 1950 and 1985, and it is therefore reasonable to assume that the fraction of the workforce with primary and secondary-school training was rising rapidly during the period studied (1960-85). It is likely that the increase in the fraction of the work-force qualified is positively correlated with the fraction of the school-age cohort enrolled in 1960, because all the developing countries probably built up education from a low base in the 1930s and 40s. This means that at least a part of the effect of education on growth identified by Barro is a consequence of the direct effect of increased education on earning power. On the other hand Weale's figures were intended to represent only an external effect whereby education raises the rate at which innovation is taken on

board. This 'endogenous growth' mechanism is discussed by Lucas (1988) and is described in section 4. It is combined with the stock-adjustment effect in Barro's results.

The importance of the stock-adjustment effect is demonstrated in the Appendix. There a demographic model is described in which the population has a life expectancy of 57. It is growing at 2% p.a., so the median age of the population is only 28. An increase in the fraction of the secondary school cohort from 0.23 to 0.53 of the cohort group over a 25-year period (for comparison with Barro's results for 1960-85) raises the effective labor force by 5-8% more than the increase in the actual labor force. In the Appendix it is demonstrated that this would imply a coefficient on the share at secondary education of 0.12 to 0.18 for a 10% increase in participation. This compares with Barro's figure of 0.23. However, it can be seen that the coefficient emerging from the stock-adjustment effect, when added to Weale's estimate of the external endogenous growth effect, gives a figure of 0.25-0.31 which is above that identified by Barro. These calculations are consistent with the higher, but less well-determined estimate of the effect of the level of education on growth presented by *World Development Report, 1991*, but they imply that the return estimates presented by Psacharopoulos (1985) are almost certainly too high. They would require a coefficient considerably higher than Barro's even without any externality present. The overall return implied is also still some way below the figures presented McMahon's (1987) study. The reasons for this ought to be investigated because education expenditure, used by McMahon ought to be a better indicator of investment in human capital than are enrolment rates or number of years of education of the workforce.

The evidence on the return to education is summarized in table 4. The macroeconomic evidence is consistent with external growth effects arising from education only if the direct return to education is well below the figures of 15% or more emerging from some cross-section studies. The studies which look at macroeconomic effects do not test for the presence of scale externalities. These might be indicated by non-linear relationships between education and economic performance and investigation of this might help to clarify the picture.

i) Rates of Return	13-27%	Primary education at top of range.
Psacharopoulos (1985)		Higher education at bottom.
<i>World Development Report, 1991</i>	5-25%	More recent surveys than those quoted by Psacharopoulos.
Behrman and Birdsall (1983, 1985)	11%	Quality-corrected survey data.
Glewwe (1991)	<6%	Ability-corrected survey data.
McMahon (1987)	20%	Cross-country regression

Baumol, Blackman and Wolff (1989) 0.038 (Primary), 0.066 (Secondary), 0.129 (Tertiary)
regression coefficients converted to annual rates

Mankiw, Romer and Weil (1992) 0.027 (secondary) regression coefficient, β_2 , converted to annual rate and divided by 0.38 to convert to a coefficient on the fraction of the school-age population attending secondary school.

World Development Report, 1991. 0.48 on years of education in 1960. 0.09 on increase in years of education in level 0 to 3. 0.04 on increase in years of education level 3 to level 9. The figure of 0.48 is expressed at an annual rate.

While it is not proven that rapid population growth is undesirable, there is a general air of concern over the expansion of the world population (Ehrlich, 1971). It is an empirical fact that educational improvements have been associated with declining fertility rates. This is partly a consequence of education lowering poverty, as the latter is associated with high fertility rates (*World Development Report, 1990*). Psacharopoulos and Woodhall (1985) in their review of the literature suggest a number of ways by which education can influence fertility. It may change perceptions of the costs and benefits of having children, and it also influences the age of marriage and reduces the infant mortality rate. Education may also change attitudes to contraception. The evidence suggests that the effect of education depends on the average level of education of the population as well as on the level of education of the individuals concerned. In countries with

literacy rates above 60%, high education appeared to be associated with reduced fertility, while where the literacy rate is below 40%, high education appeared to be associated with increased fertility. Thus increases in school enrolment rates were initially associated with increases in fertility, and it seems that the enrolment rate has to rise above 75% before a sustained decline can be anticipated. The average developing country is now well over this threshold (see footnote 11, p.38)

Psacharopoulos and Woodhall arrived at the following conclusions. Education is unlikely to reduce fertility in all circumstances. It seems that the initial conditions vis-a-vis literacy are especially important. Thus, for the least literate societies evidence points in the direction that increments in education lead to increases in fertility. Nevertheless, in the long run it is usually the case that increasing education will ultimately reduce fertility. Education of females, especially girls, is usually more effective at affecting fertility than educating males. Finally, education is more likely to reduce fertility in urban areas than in rural areas. The link between education and fertility is not straightforward, but, at the levels of education found in most developing countries nowadays, education does appear to be a force reducing fertility.

What is needed in this area is a better understanding of the economics of household and family development. Caldwell (1982) presents a theory for fertility decline based on the costs of rearing children. He presents an analysis of how households evaluate the costs and benefits of having children. Not surprisingly, to explain a declining fertility rate it is suggested that the expected costs of having a child increase with education, with proportionate changes in the benefits not offsetting this. This is argued to be related to both the indirect costs (opportunity costs) and the direct costs of education, fees, etc. This approach is similar in spirit to the human capital model, see Becker (1964). The *World Development Report* 1990, however, suggests that the most effective way to deal with high fertility rates is to improve family planning services.

The results of careful cross-section studies are presented by Rosenzweig (1990). He suggests that fertility of landless laborers in India in 1971 is positively-linked to child wages and to adult male wages but negatively-linked to adult female wages. Mother's schooling was not an important influence in the results of this study. It is not clear, however, whether fertility is responding to the difference between wage rates for educated and uneducated labor. School enrolment rates respond negatively to child wages and positively to fathers' wages but, once again the results do not actually indicate how they respond to the return to education.

Perhaps the best cross-section evidence for a link between the return to education and fertility is offered by Rosenzweig's assessment of the green revolution. In areas covered by the Intensive Agricultural Development Program (IADP) the return to education seems to have been

raised, although it is not clear that the change is statistically significant. In the same areas there was a marked reduction in fertility. The fraction of the relevant cohort with no primary schooling fell by slightly more in the IADP areas than in the other areas (but since the initial fraction was smaller, the percentage reduction in non-education was much larger).

These data cannot be said to be very precise but they do provide supporting rather than contradictory evidence for the view that parents see increased human capital per child as a substitute for numbers of children and that their willingness to substitute human capital per child for children depends on the return to education. It is also suggested that the magnitude of the effect may be restricted by the costs of fertility control.

Complementing these studies are macroeconomic analyses. These pick up the inverse relationship between investing in human capital and investing in children and extend the analysis to the whole economy by integrating these decisions with the consumption/saving decision. The model presented by Barro and Becker (1989) is discussed in detail in sections 3 and 4 with the results of simulation experiments. The cross-country macroeconomic evidence is discussed after these simulations. Rosenzweig (1988) makes the point that macroeconomic comparisons generally suggest much more powerful links than do survey-based results and the reason for this is not completely clear. The survey-based results may be missing effects which are external to the individual but internal to the country or the coefficients may be biased due to measurement error. On the other hand the cross-country studies may well suffer from omitted variable bias, so that effects are being attributed to education rather than to some other variables.

Barro (1991) studies the economic factors which influence fertility rates. He finds from the cross-section of countries that an increase of 10% of the relevant age group attending primary school reduces the number of children born to each woman by 0.13. An increase of the secondary school population by 10% of the cohort reduces the fertility rate by 0.26. The infant mortality rate (deaths up to the age of 4) is an explanatory variable, but the effect is not very different if the net fertility rate (number of children surviving to the age of 4) is studied instead. The level of GDP in 1960 is included as a regressor. This is not statistically significant unless dummies are included for Latin America and Africa; there is, however, no obvious reason why dummies should be introduced for these regions. When the latter dummies are present the effect of primary education on fertility rises from 0.13 to 0.16 children while that of secondary education falls from 0.26 to 0.24; it does not, therefore change markedly the conclusions to be drawn from this about the effect of education on fertility. Barro does not test the restriction that the coefficients on both types of education are equal and it is not possible to do this with the results as they are presented, but, in view of the t-statistics shown, it would probably be accepted.

Table 5 **Education and Fertility**

Regression explaining Fertility, Barro (p. 423)

Cons	GDP 60	Prim- ary	Second- ary	g ² /y	REV	ASS	PPI DEV	R ²
6.08 (0.35)	-0.105 (0.069)	-1.56 (0.41)	-3.01 (0.59)	1.0 (1.5)	-0.13 (0.32)	1.45 (0.55)	0.40 (0.26)	0.72

There are 98 observations in each regression

PERTNET	No of children per woman surviving beyond the age of 4. Average of 1960-85.
GDP60	GDP <i>per capita</i> in 1960 at international prices
Primary	primary school enrolment rate in 1960
Secondary	secondary school enrolment rate in 1960
g ² /y	average ratio of government consumption (excluding defence and education) to GDP, 1970-85
REV	Average number of revolutions and <i>coups</i> per year, 1960-85.
ASS	Number of assassinations per million population per year, 1960-85
PPIDEV	Deviation of price of investment goods from sample mean in 1960

Neither the model nor Barro's data distinguish the education of men from the education of women. Psacharopoulos and Woodhall (1985) argue that in practice there are important differences⁷. The model focuses on education as affecting the cost of raising children through reducing the labor time that they have available for work, but there are likely to be a number of other important effects. First of all the desire and the ability to control fertility are not the same thing. A reasonable level of education may be necessary for women to be able to understand the consequences of fertility control. Secondly, in societies where women are poorly educated, fertility decisions may be made by men who do not regard the costs of bearing and raising children in quite the same light as do women. Thirdly, the return to education of women may be different from that of men because women are likely to drop out of the labor force for at least part of their working lives. The willingness of parents to educate their daughters may depend on whether society functions by means of a dowry or whether the effects of education can be capitalized into a bride price.

2.4 Education and Health

The relationship between education and health has been discussed by Cochrane et al. (1980) and more recently by Kenkel (1991) and Gomes-Nato et al. (1992). Education feeds through to influencing health by its affects on mortality rates, disease and nutrition. The Cochrane et al. study found education to be an important variable in stemming disease and thus reducing mortality rates. The effect was found to be even stronger than per capita income and doctors per

⁷Although it cannot be said that the results presented by Rosenzweig (1990) and discussed above support this view.

capita. One of the strongest relationships in this area is that between parental, in particular the mother's, education and a child's health. As Psacharopoulos and Woodhall (1985) note "The evidence is unequivocal: educated parents, particularly mothers, have better-nourished children who are less likely to die in infancy than the children of uneducated parents. On average, one additional year of schooling for a mother results in a reduction of 9 per 1,000 in child or infant mortality." This conclusion is reached not from a single regression equation but from the pooling of a number of cross-section studies.

Although the evidence of a correlation is clear, the direction of causality is not so apparent. For example, better educated mother's may generate higher incomes and therefore the household may find itself with improvements in nutrition and other factors. The interaction between health and education is complex. Grossman (1972) suggested that schooling increases the efficiency of household health production, which was subsequently supported by empirical studies by Grossman (1976) and Berger and Leigh (1989). Fuchs (1982), however, argues that people with different levels of schooling probably differ in unobservable ways, such as their rate of time preference. It is suggested that good health might be a consequence of the unobservables rather than good schooling. The recent studies by Kenkel (1991) and Gomes-Nato et al. (1992) provide some new insights into this relationship. They focus on the complementarities that exist between health and schooling, an issue which has also been addressed by Leslie and Jamison (1990) and Lockheed and Verspoor (1991).

Kenkel (1991) examines the relationship by focusing on the inputs into a household's production of health. The hypothesis that he tests is whether schooling improves allocative efficiency, that is the choice of inputs, by improving individuals' health knowledge. He tests the hypothesis on 1985 U.S. data and estimates the separate effects of health knowledge and schooling on consumption of cigarettes, alcohol and exercise. (In the developing economy context other variables, such as cooking techniques, water treatment, etc. could be considered as well.) His results suggest that schooling's effect on the allocative efficiency of the household production of health is not the main reason schooling is linked to health. He claims that the observed correlation might be due to unobservable differences across individuals, as suggested by Fuchs (1982).

The Gomes-Nato et al. study is an empirical one making use of a unique panel data set from northeast Brazil. Their main finding is that nutrition and health strongly affect student grade performance and student achievement. Because well-nourished children perform more satisfactorily, it is suggested that school feeding programs could be used to improve overall educational attainment levels. Thus educational expenditures in developing countries should

account for amounts devoted to feeding programs. The *World Development Report* 1990 cites several studies demonstrating a clear connection between nutrition and learning capacities.

Table 6 **Studies of the Link between Education and Health**

Cochrane <i>et al.</i> (1980).	Survey of Range of Studies	The studies looked at the link between parental education and child mortality. Data for 17 countries were studied. A significant relationship was found in all but two. In a further 7 studies controls were made for other variables such as income or indicators of income.
Kenkel (1991).	The Effects of Education on Health in USA	Survey of health knowledge and behavior. 14,177 males and 19,453 females surveyed in 1985 by the Health Promotion/Disease Prevention supplement to the 1985 Health Interview Survey.
Gomes-Nato, Hanushek, Leite and Frota-Bezzera. (1992).	Survey of 1516 students in Brazil in 1985. 387 surveyed in 1987.	Study looked at effects of health on school performance.

It would be desirable that these studies should be complemented by cross-country comparisons similar to those used to assess education, fertility and growth. Dasgupta and Weale (1992) provide preliminary evidence to suggest that health improvements are linked with economic improvements but more work needs to be done in this area.

Summary

This survey of studies of the effect of education leads to a number of important conclusions. First of all there is very little doubt that education is associated with increased earning power for individuals. Nevertheless there are reasons for believing that an estimated return of 20% p.a. or more from one year of schooling is too high. The estimates are calculated in a way which does not adjust for quality, does not reflect the fact that the return comes from literacy and numeracy skills rather than from education *per se*, and does not take account of the fact that people from a more advantageous background are more likely to be educated. Macroeconomic analyses of the links between education and growth are consistent with an external benefit linking

education to growth in productivity over and above the productivity effects internal to the educated, only if direct rates of return are considerably lower than those shown by the cross-section studies.

There are well-documented effects linking education to health, but, from the global perspective, much more important external effects of education are almost certainly its influence on fertility and on technical progress; it is desirable to examine these externalities further. In the next section a model is explained which treats fertility as a choice variable of the same type as consumption and saving. Study of this model sheds light on the nature of the link between education and fertility. The model lends itself happily to an analysis of this at the same time as the link between education and productivity is being investigated.

3. A Model of Fertility, Investment and Externalities from Education

The previous sections have discussed the evidence that there is link between education attainment, fertility and economic growth generated by technical progress. Further, it was suggested that the link between education and fertility might well be an economic link, with the fertility decision being linked to the consumption/saving decision. This suggests that it might be helpful to explore further the linkages between education, fertility and technical progress by means of a formal model. Simulation of this model allows one to understand the nature of the externalities which link education to fertility and technical progress. This section develops the model presented by Barro and Becker (1988, 1989) in order to investigate these links. The model offers a formal explanation of why there should be a link between education and fertility. It demonstrates that the rate of fertility is inversely related to the level of education. At low levels of education a combination of low productivity and high fertility point to a Malthusian nightmare.

The model is set out in stages. First of all Barro and Becker's model is described. Parameter values are chosen and simulations are carried out in order to investigate the sensitivity of the solution to these parameters. The model is then extended in two stages. In section 3.4, a human capital model of investment in education is integrated with the model. This makes it possible to illustrate the observed link between fertility and education, making the assumption that technical progress is exogenous. In section 4, the model is extended further, so that the rate of growth is dependent on the duration of education. The simulation properties are investigated and the links between education, technical progress and fertility are found to be broadly consistent with Barro's (1991) results.

The model assumes that populations grow by means of pathogenesis, but that the fertility rate is an endogenous variable. The supply side of the model is not very controversial; output is produced by means of labor and capital; labor is supplied inelastically, but the availability

of labor depends on the time households spend looking after children and that children spend undergoing education broadly defined. The utility function which determines the choice between spending and saving is more unusual. As discussed by Meade (1966) parents show a degree of altruism for their offspring: they pay the costs of rearing them and they aim to leave them a bequest of capital; this influences strongly parents' saving and in fact has the implication that children become a substitute for capital accumulation.

The most controversial aspect of the model is that reproduction is seen as an economic decision. Parents choose how many children to have with the aim of maximizing their utility function, bearing in mind the costs of rearing children. One can think of each agent in the i th generation as maximizing a dynastic welfare function, which arises from a process of infinite regress. Each agent is concerned about the welfare of its children. It is not directly concerned about the welfare of its grandchildren, but this does matter because they influence the welfare of the children, and the outcome of this is that dynastic welfare depends on the consumption of all future generations weighted by the extent of the altruism that each generation has for its children.

At the same time, less unusually, there is a dynastic budget constraint which says simply that the discounted value of the dynastic income must equal the discounted sum of dynastic expenditure including the cost of raising children, and a production function of a conventional form which shows the output arising from inputs of labor and capital. Barro and Becker assume exogenous Harrod-neutral technical progress.

From these building blocks an endogenous fertility rate can be calculated. In the steady state, in which wage rates and the cost of child-rearing are both growing at constant rates, it turns out that the fertility rate depends positively on the degree of altruism (the extent to which parents derive utility from their children's utility) and on the rate of interest, but negatively on the rate of technical progress. These two effects can be easily understood. A high rate of interest raises the cost of future consumption (and future utility) compared with current utility. Children offer an alternative means of future utility. A high rate of growth must go with a reduction in fertility because, at any rate of interest, they are both associated with greater preference for present consumption.

Models of this type are obviously open to the objection that they imply a greater degree of planning and awareness of the future than is believed to be the case, particularly among poorly educated people in underdeveloped countries. But there is little doubt that people do see children as a means of saving if only to provide for them in their old age, and it is also clear that people are concerned about the welfare of their children. The great advantage of this model is that

it considers jointly saving in the form of capital goods and saving in the form of children. The use of a dynastic utility function has the implication that people are implicitly concerned about the welfare of their distant descendants. But if only the utility of parents and children were considered, it would be necessary to modify the budget constraint by including a target terminal value of children's bequest, and this would introduce an arbitrary element.

Here the Barro-Becker model is extended by the introduction of choice about the duration of education and by the assumption that the overall level of labor productivity depends on the cumulated total of past education, so that the growth rate becomes endogenous in the manner described by Lucas (1988). The extension set out here is designed for comparative static analysis, and it is therefore considerably simpler than the dynamic model described by Becker, Murphy and Tamura (1990) (see section 3.4); it is subsequently also argued that the extensions made here are more realistic than those of Becker, Murphy and Tamura. In common with empirical evidence, it represents the main cost of education as being the opportunity for child labor foregone, so that the duration of education chosen by the rational parent depends on the return to education relative to the interest rate and trend growth rate. The trend rate of growth is directly proportional to the duration of education chosen by the rational parent but, since the effect on growth is external, the rational parent forms its choice taking the rate of growth as given.

The steady-state properties of the model are investigated by means of simulation using imposed parameter values, and the sensitivity of the result to these parameters is investigated. Conclusions are drawn about the mechanisms by which education may have effects on fertility, fixed investment and economic growth.

3.1 *The Barro-Becker Model*

First of all the model is explained and parameter sensitivity is explored. Each household head in the i th generation is assumed to derive utility from its consumption and that of its n_i direct descendants

$$U_i = c_i^\sigma + \alpha n_i^{-\epsilon} U_{i+1} \quad (1)$$

where $\alpha n_i^{-\epsilon}$ is the utility that each parent derives from the utility of each child. With $\epsilon > 0$ it can be seen that it is declining in the number of children. α measures the utility which a parent would gain from the utility of a single child and can be described as an altruism parameter. The elasticity of utility with respect to consumption is $\sigma > 0$.

Each household head also faces a budget constraint, which states that total income, from wages w_i^* and capital $r_i k_i^*$ plus initial endowment, k_i^* can be spent on consumption, c_i^* , or on the costs of raising children (β_i^* per child) or providing an endowment (k_{i+1}^*) per child.

$$w_i^* + (1+r_i)k_i^* = c_i^* + n_i(\beta_i^* + k_{i+1}^*) \quad (2)$$

The optimization problem is best considered in terms of the dynastic utility function

$$U_0 = \sum_{i=0}^{\infty} \alpha^i N_i^{1-\epsilon} c_i^{*\epsilon} \quad (3)$$

where $N_i = \prod_{j=1}^{i-1} n_j$ and is the size of the i th generation descended from a single household head in the 0th generation. This dynastic utility function is maximized subject to the intertemporal budget constraint

$$k_0^* + \sum_{i=1}^{\infty} d_i N_i w_i^* = \sum_{i=1}^{\infty} d_i (N_i c_i^* + N_{i+1} \beta_i^*) \quad (4)$$

where $d_i = \prod_{j=1}^{i-1} (1+r_j)$ and is the discount factor showing the present discounted value of one unit of expenditure by generation i . The budget constraint shows the present value of the initial endowment, k_0^* , plus dynastic labor income equal to the discounted value of total consumption and the total discounted costs of raising children.

Utility is maximized for each value of N_i (and thus n_i) and c_i^* separately. Each generation makes its own choice taking the choices of the other generations as given, making the solution a Nash equilibrium. This optimization exercise leads to equations for consumption and for the rate of fertility. These two equations taken together are shown to lead to a consumption function

$$c_i^* = \frac{\sigma}{1-\epsilon-\sigma} [\beta_{i-1}^* (1+r_i) - w_i^*] \quad (5)$$

while the fertility rate also depends on the costs of raising children and the degree of altruism as well as the wage rate and interest rate

$$n_i^* = [\alpha(1+r_{i+1})] \left[\frac{\beta_{i-1}^* (1+r_i) - w_i^*}{\beta_i^* (1+r_{i+1}) - w_{i+1}^*} \right]^{1-\sigma} \quad (6)$$

The production structure must now be specified. Here it is necessary to be more specific than Barro and Becker, because the model is to be solved subsequently, and a Cobb-

Douglas production function for output per effective worker is therefore assumed. Growth at rate g is assumed to be labor-augmenting technical progress. For the time being, both the level of labor productivity and the growth rate are taken to be exogenous. The level of output gross of depreciation is y and is a function f of the capital stock per worker

$$y_i = (1+g)^i (k_i^*/(1+g))^{\alpha} \quad (7)$$

With exogenous growth at rate g , one actual worker is equivalent to $(1+g)^i$ effective workers. It then follows that the consumption level, capital stock and wage rate per effective worker are simply linked to their actual values.

$$c_i = c_i^*/(1+g)^i; \quad k_i = k_i^*/(1+g)^i; \quad w_i = w_i^*/(1+g)^i \quad (8)$$

With a rate of depreciation of capital, Δ , the normal relations for the rate of interest and the wage rate hold

$$r_i = f'(k_i) - \Delta k_i; \quad w_i = [f(k_i) - k_i f'(k_i) - \Delta k_i] \quad (9)$$

The cost of rearing each child, β_i , is specified in terms of goods input, a , and labor time, b , per unit of effective labor, with β_i^* being the absolute cost per worker

$$\beta_i = a + b w_i = \beta_i^*/(1+g)^i \quad (10)$$

with the assumptions that each adult spends a fraction b of his available labor time rearing each child and that the goods input needed to raise each child grows in line with the exogenous growth in labor productivity.

The budget constraint for generation i can be set out again in terms of effective units of labor (after dividing by $(1+g)^i$)

$$(1 - b n_{i+1}) [w_i + (1+r_i) k_i] = c_i + n_i [a + (1+g)(1 - b n_{i+1}) k_{i+1}] \quad (11)$$

This says that the output per unit of labor (man-hour or rather man-generation), multiplied by the fraction of available time which is devoted to labor rather than to child-bearing, is equal to consumption plus the goods which are taken up in rearing children plus the bequests which have to be left to children. These bequests depend not only on the number of children, but also on the rate of growth, because everything is defined in terms of effective units of labor. They are multiplied by the fraction of time available which the i th generation devotes to work rather than to raising its n_{i+1} children.

The dynamic path described by these equations is of some complexity, because they form a non-linear differential system. However, a great deal of useful analysis can be done by exploring the properties of the model in steady states. This will allow us to come to some view about the effects of changes in the rate of growth or in the cost of rearing children on fertility and fixed investment.

In the steady state, the time subscripts may be dropped and the rate of labor productivity growth becomes simply a function of the level of expenditure on child-rearing. Equation (6) reduces to a simple form for the fertility rate

$$n^{\epsilon} = \frac{\alpha(1+r)}{(1+g)^{1-\sigma}} \quad (12)$$

suggesting that, with a constant rate of interest, higher growth will be associated with lower fertility. Of course, this partial analysis may not survive once the effects of a change in the rate of growth on the interest rate are taken into account.

The second equation which drives the model is the intertemporal budget constraint (11). Consumption is eliminated using (5) so that the budget constraint becomes

$$f(k) + k = \frac{\sigma}{1-\epsilon-\sigma} \left[\beta \frac{1+r}{1+g} - w \right] + n \left[\beta + (1+g)k \right] + bnk[1+r-n(1+g)] \quad (13)$$

One can then substitute for w , r and $f(k)$ using the production function and its derivatives and for β using equations (10), so that, with suitable parameter values, the model can be solved.

Before presenting this solution, one point about the model should be noted. Equation (1) implies that, in the steady state dynastic utility is given as

$$U = \frac{c^{\sigma}}{1-\alpha n^{1-\epsilon}} \quad (14)$$

Combining this with the expression for the rate of fertility implies that, for dynastic utility to be bounded

$$(1+r) > n(1+g) \quad (15)$$

This is the standard result that the rate of growth, $n(1+g)$, must be below the rate of interest. But there is a second implication of equation (14). A social planner who aimed to maximize the dynastic

utility function would do so by raising pursuing policies which raised the rate of fertility to the point where dynastic utility became infinite. In using this model, one must therefore be cautious of interpreting the value of the dynastic utility function as a measure of welfare.

3.2 *Parameter Values and the Model Solution*

A certain amount of care is necessary in the choice of parameter values and in the interpretation of the results of the model is necessary because the period is a generation rather than a year. In order to interpret the results in a more conventional framework, one can assume that the generation lasts for 25 years. This means that a depreciation rate of 5% p.a. of the fixed capital stock turns into a depreciation factor of 72%. A growth rate of 0.5% p.a. in the population or the efficiency of labor turns into 13% per generation. One of 1% p.a. turns into 28% per generation and one of 2% per p.a. turns into 64% per generation. With these figures in mind parameter values can be presented.

The exogenous increase in labor productivity is assumed to be 0.608, corresponding to 2% p.a. (the average rate of *per capita* growth identified by Barro was 2.2% p.a.) and the depreciation rate is 0.72 corresponding to 5% p.a. The degree of altruism is taken as 0.3, meaning that a parent is concerned about the welfare of a single child only 30% as much as they are concerned about their own welfare. However, the elasticity with which this declines with the number of children, ϵ , is taken as 0.45. The elasticity of utility with respect to consumption, σ , is 0.4.

The costs of raising children are assumed to be 10% of potential labor time and 20% of potential goods output. These may seem rather high but figures of this magnitude are needed to keep the rate of fertility which the model delivers down to a 'reasonable' level.

The parameter values are summarized in the following table:

Table 7		Parameter Values		
$\alpha = 0.3$	$a = 0.2$	$b = 0.1$	$\Delta = 0.28$	
$G = 0.608$	$\epsilon = 0.45$	$\sigma = 0.4$		

With these parameter values the model solves to give the results shown in table 8.

Table 8	Model Solution
Fertility Rate	1.1% p.a.
Capital-Output Ratio	1.93 per annum
Investment Ratio	7.5%
Interest Rate	6.83% p.a.

3.3 *Sensitivity Analysis*

The sensitivity of these results can be explored by variation in the key parameters of the model. Variations in three parameters are considered. These are the exogenous rate of growth, the degree of altruism and the cost of raising children. The following graphs show the effects of these variations.

The first and second panels of figure 1 demonstrate just how sensitive the results are to the degree of altruism and to the cost of raising children. An apparently small increase in the altruism parameter leads to a rapid increase in fertility. The increase in fertility caused by an increased liking for children is associated with an increase in the capital-output ratio and a reduction in the rate of interest not shown on the graph. A reduction in the cost of raising children, represented by a reduction in parameter a of equation (10) also leads to an increase in fertility. But because this is caused by a lower cost of children and not a greater liking for them, the increase in fertility is in fact associated with a reduction in the capital-output ratio and a rise in the interest rate.

The third panel demonstrates that, although a higher rate of growth reduces fertility at a given interest rate, in the solution of the full model a higher rate of growth raises the equilibrium interest rate by so much that the fertility rate is increased in the complete solution. Faster growth cannot, on its own, lead to a slowdown in fertility. This result seems to persist for a wide range of parameters. Searching over figures which led to plausible rates of fertility, it was not possible to find a situation in which faster growth in productivity was associated with lower fertility.

3.4 *Education and Fertility*

We can now look at the case where education affects the level of productivity of an individual but not its overall growth rate. This is not quite as straightforward as it might seem. The

model above is set out in discrete time, with each interval being one generation or twenty-five years. Furthermore it is assumed that children do not work at all in the generation in which they are born, and the labor cost of raising children is therefore adult time foregone. This simple structure is not sufficient for looking at the effects of education.

Becker, Murphy, and Tamura (1990) suggest an extension of the model. They assume that adults can vary the labor time which they devote to raising children and that the human capital of the children is a function of this labor input. Secondly, they assume that the human capital generated per unit of labor input is increasing for relatively small labor inputs. Neither of these assumptions are satisfactory. On the first point, the main cost of education is not the time of the teacher but the foregone labor time of the person being taught, a point recognized by Rosenzweig (1990). On the issue of increasing returns, there is only limited support for their view. Denison's (1967) suggestion that the return on education is about 5% p.a. for up to 8 years and 8% p.a. beyond that indeed supports the argument. But Card and Krueger (1992), discussing the United States, suggest roughly constant returns (labor income rising exponentially with the duration of education), while the figures quoted by Psacharopoulos (1985) suggest a diminishing social return. In the light of the empirical evidence, it seems perfectly satisfactory to settle for a linear relation between length of education and future earning power. This does have the implication that it removes the multiple equilibria from Becker, Murphy, and Tamura's model⁸ but, without a clear empirical basis for the non-linearity, this is probably sensible.

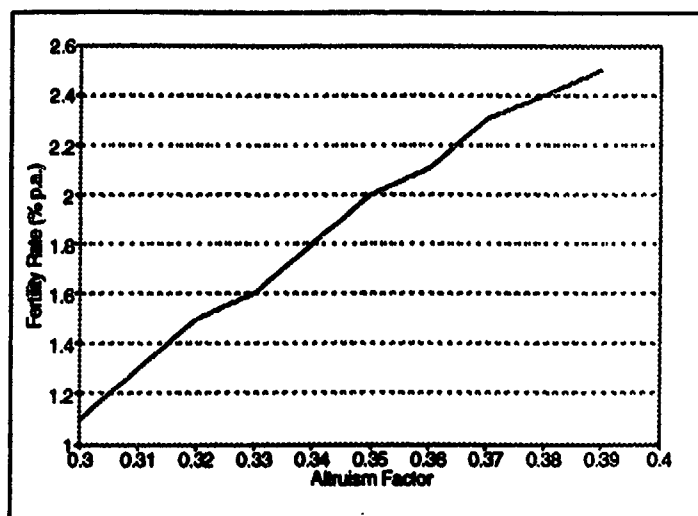
The basic changes made to the Barro/Becker model are therefore to assume that children can divide their time between work and education. The wage that they earn once education terminates depends exponentially on the duration of their education. But the introduction of child labor requires some care. Even if earning capacity is attributed to children, in terms of some adult equivalent, the model is still not satisfactory. The discrete-time structure implies that someone who is educated will have to wait a whole generation before reaping any benefit from that education. This will grossly undervalue the benefits of education compared with the more realistic situation in which the benefits of education accrue immediately after education is concluded. A number of modifications must therefore be made to the model.

⁸The problem is perhaps the issue of widening versus deepening. Returns may be higher if more people are educated as Lucas (1988) suggested. This question undoubtedly merits further investigation. None of the empirical studies considered hitherto have investigated the issue, but it is of course possible that it might explain the role of the dummy variables observed by Barro (1991) for Africa and Latin America.

Figure 1 Influences on the Fertility Rate

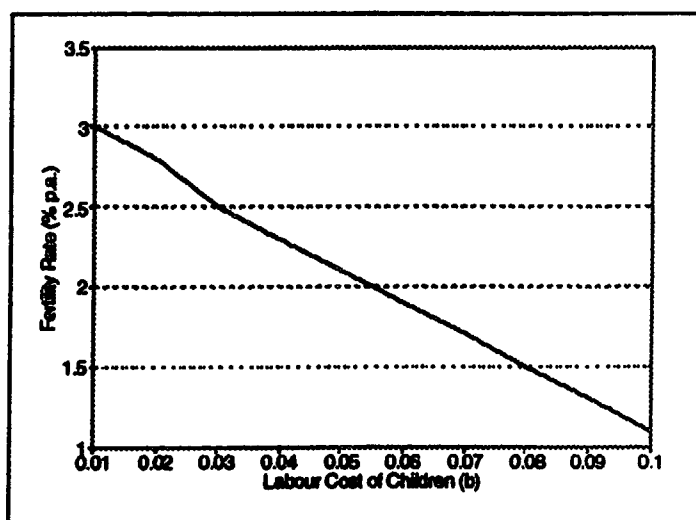
i) The Effects of Altruism

The altruism parameter indicates the importance that parents attach to their children's welfare relative to their own welfare.

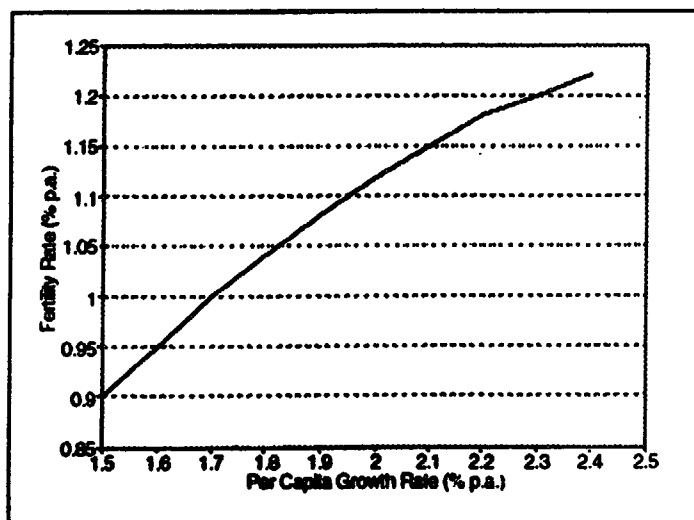


ii) The Impact of the Cost of Raising Children

The cost is measured as the fraction of adult labour time allocated per child.



iii) The Effect of Growth in *per Capita* Income



The interval during which the child grows up must be treated in continuous time if the work/ education choice is to be modelled properly. For the purposes of this model, it is assumed that child labor income accrues to its parent. For a child starting work after a fraction b_i' of the i th period, we can calculate the discounted value of child labor income valued at the start of the period. The discounted value of child labor⁹ at the start of the period is, taking account of trend growth,

$$w_i \int_{b_i'}^1 e^{Gt-R_i t} dt \quad (16)$$

where G is the continuous time equivalent of the growth rate and R_i is the continuous time equivalent of the rate of interest so that

$$G = \log(1+g); \quad R_i = \log(1+r_i) \quad (17)$$

However, the value of the adult wage discounted back to the start of the period is

$$\int_0^1 w_i e^{Gt-R_i t} dt = w_i (1 - e^{G-R_i}) / (R_i - G) \quad (18)$$

and the child wage calculated in equation (16) is therefore divided by $(1 - e^{G-R_i}) / (R_i - G)$ so as to bring it to par with the adult wage.

The effect of education on the wage rate can be represented by the simple exponential function

$$w_i = W_i e^{\kappa b_i'} = W_i^* e^{\kappa b_i'} / (1+g)^i \quad (19)$$

where W_i is the notional wage per unit of effective labor paid to someone who is uneducated and b_i' is the fraction of the period of youth for which the person concerned has been educated. κ is the extent to which earning power is raised per unit period of education. This then defines the effective child wage

⁹This assumes that the child wage rate is the same as the adult wage rate. This is perhaps reasonable if one is looking at a developing country for which the optimal values of b_i' are of the order of 0.6 or more. If children are paid markedly less than adults the opportunity cost of education is reduced.

$$u_i^* = W_i e^{w_i'} \frac{e^{(G-R_i)b_i'} - e^{G-R_i}}{(1-e^{G-R_i})/(R_i-G)} \quad (20)$$

with $u_i^* = u_i(1+g)^i$ defining the actual wage. This income should be included in the budget constraint, so that equation (2) becomes

$$w_i^* + n_i u_i^* + (1+r_i)k_i^* = c_i^* + n_i(\beta_i^* + k_{i+1}^*) \quad (21)$$

and the associated dynastic budget constraint is

$$k_0^* + \sum_{i=0}^{\infty} d_i(N_i w_i^* + N_{i+1} u_i^*) = \sum_{i=0}^{\infty} d_i(N_i c_i^* + N_{i+1} \beta_i^*) \quad (22)$$

It can be seen that, if the income from child labor is an exogenous variable like the adult wage rate, then we can define the net cost of raising children as $\beta^{*}_{i+1} = \beta_i^* - u_i^*$ and the analysis proceeds as before. However, things are changed once the duration of education is chosen by the parent. Now it is necessary to optimize over this variable, b_i' , as well as over consumption, c_i^* , and family size, n_i or its cumulant, N_i .

In fact, the first-order conditions in equations (5) and (6) are unchanged by the link between wage rates, income from child labor and education. β^{*}_{i+1} is simply replaced by β^{*}_{i+1} . The education decision, if left to the private sector, is simply the maximization of the dynastic budget constraint over the education duration variable b_i' . The life-time income of the child is the sum of the discounted value of its child and adult labor, $u_i^* + w_{i+1}^*(1+g)/(1+r_i)$. Maximization of this over b_i' yields the optimal duration of education,

$$b_i' = 2 - \frac{1}{R_i - G} \log \frac{\kappa}{\kappa + G - R_i} \quad (23)$$

but also subject to the requirement that $0 < b_i' < 1$.

The solution of the model is scarcely more complicated than in the previous case. b_i' is now an endogenous parameter determined by the endogenous rate of interest. Simulations are carried out as before, with only one change made. Now that child labor is recognized, the adult labor involved in looking after children has to be raised, and a figure of 0.3 per child is used.

The first panel on figure 2 shows the link between the duration of education and the excess of the interest rate over the return to education. It is, in effect, a plot of equation (23), with

the growth rate remaining at 2% p.a. Since the growth rate is constant, it is not surprising that the duration of education falls off sharply as the interest rate rises relative to the return on education.

The next two graphs show the link between the return to education and the rate of fertility. Rather surprisingly, as the rate of return to education increases, the rate of fertility increases as well. The reason for this can be understood by reference to the third panel in conjunction with equation (23). As the rate of return on education increases, the rate of interest increases by more, so that the discounted benefit of education is actually reduced. Since the interest rate is determined endogenously as part of the model, it has not proved possible to unravel why the interest rate rises in response to an increase in the rate of return to education. But the consequence of the increased interest rate is that education becomes more expensive. The period of education is therefore shortened and, since children become cheaper in terms of net labor time, the rate of fertility actually increases. However, if, as in the third panel, one looks at the relationship between the excess of the rate of interest over the return to education, and the rate of fertility, the expected relationship is observed. The greater the excess of the interest rate over the return to education, the lower is the optimal period of education (figure 2i) and therefore, as shown in the third panel, the higher the rate of optimal fertility.

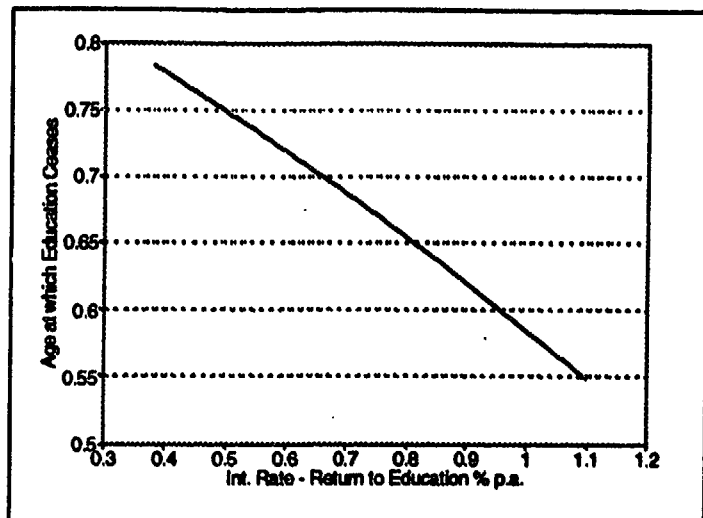
It should be noted that the perverse relationship shown in the second panel would not be found if the rate of interest were fixed exogenously. In the closed economy discussed here, it is true that each individual treats the rate of interest as fixed but it is, nevertheless, sensitive to their aggregate spending and saving decisions. In a small developing country which allows free inflow of capital, the interest rate may be influenced by world capital markets. In such circumstances a rising return to education will have the effect of reducing the rate of fertility rather than leading to the increase shown here. A second point to note is the great sensitivity of the results to the (private) return to education. It is unlikely that this will ever be measured with great precision, and, in any case, there must be a great deal of *ex ante* uncertainty.

The links between education and economic growth are now discussed. This is followed by an extension of the model so as to demonstrate possible links between the level of education and long-term economic growth.

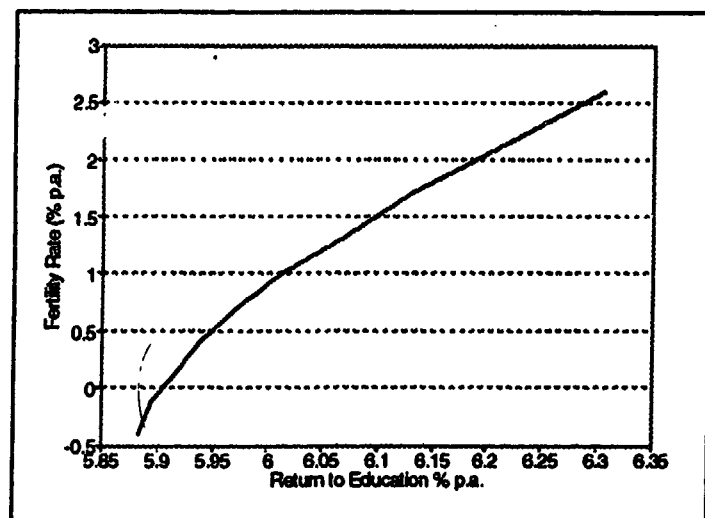
**Figure 2 The Effect of the
Return to Education**

**i) The Age at which Education
Ceases**

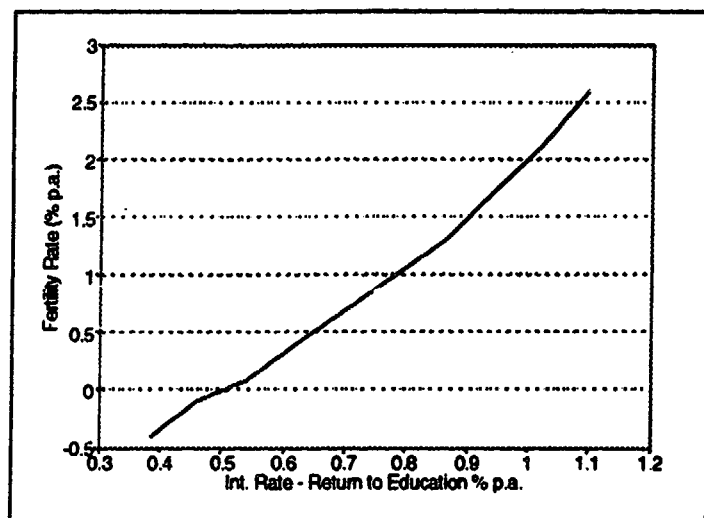
This is shown, as a fraction of the total
period of 'youth', plotted against the
interest rate-return to education



**ii) The Return to Education and the
Fertility Rate**



**iii) The Return to Education Relative
to the Interest Rate and the
Fertility Rate**



4. Modelling the Effects of Education on Growth and Development

The analysis of education so far has been in microeconomic terms. Individuals are assumed to choose the optimal duration of education so as to maximize the value of the dynastic budget constraint. Children are educated to the point at which the discounted value of extra income generated by marginal education is just equal to the total cost of that education. In the model set out in section 3 economic growth was purely exogenous labor-saving technical progress.

In fact, as was observed in the discussion of Barro's results, there are three possible links between education and economic growth. First of all, education raises the effective size of the labor force because it increases the labor productivity of individuals. During a period in which the educational standard of the population is rising, this stock-adjustment effect will lead to economic growth. It was argued, using the example described in the Appendix, that this might account for about half of the effect described by Barro. The second and third links between education and growth are described by Lucas (1988). His suggestions are firstly that knowledge does not completely disappear with the death of an educated generation, but that some of it is inherited by their successors. Secondly, at a social level, a high average level of education raises the benefit of education to any individual. A consequence of these effects is that high levels of education will be associated with rapid rates of technical progress.

This section begins with an outline of models of economic growth and development. Simulations of the model are then carried out in order to assess possible effects between education, growth and fertility.

4.1 *Conventional Neo-Classical Growth Models*

The relationship between education and economic development at the broad macroeconomic level has largely been analyzed within the framework of neo-classical growth theory models developed by Solow (1956). Denison (1961) advocated an analysis of education based on a growth accounting framework, using an aggregate production function $Y=F(K,L)$, where Y is output, K is capital and L is labor. Using this structure estimates of the effects of education on output can be made. Denison's own calculations showed that between 1930 and 1960 around 23% of the rate of growth in U.S. output is explained by the increased level of education of the workforce. Nadiri (1972) used this approach to analyze developing economies and his study presented a mix of results. For some countries, such as Ghana, there were strong educational affects (23.2% of output growth is explained by education), whereas for others like Colombia, it was relatively low (4.1% of output growth is explained by education).

More recently Lucas (1988) has criticized the neo-classical growth theory model as a vehicle for explaining the mechanics of development. At this point it is useful to summarize the main characteristics of the neo-classical growth model. The Solow growth model in its simplest guise is developed by assuming a closed economy, competitive markets, rational agents and constant returns to scale. Fertility is taken to be exogenous, as is the growth in the level of technology. These two assumptions preclude the possibility of externality effects feeding through education via technical change, fertility, nutrition and other indirect effects. The model aims to solve for a (*per capita*) consumption path. Along a balanced path the rate of growth of per-capita magnitudes is proportional to the exogenous rate of technical change and the inverse of the share of labor in output. The Solow model predicts that economies with access to similar technologies will converge to a common balanced growth path.

The Solow neo-classical growth model was a major contribution to economic theory in that it emphasized the distinction between growth effects (changes in parameters that affect growth rates along balanced paths) and level effects (changes in parameters that raise or lower the balanced growth path but not its rate of change). In this context changes in savings rates turn out to have level effects, higher savings affect output levels but not growth in output. The same can be said of market inefficiency effects, such as trade barriers. The removal of trade barriers will have a desirable effect on output levels, but growth will not be affected. Denison used the Solow growth model to assess the factors contributing to growth in the United States. Lucas (1988) made the following comment on this approach.

"In the main, the theory adds little to what common sense would tell us about the direction of each effect - it is easy enough to guess which changes stimulate production, hence savings, and hence (at least for a time) economic growth. Yet most such changes, quantified, have trivial effects: The growth rate of an entire economy is not an easy thing to move around."

Lucas goes on to remark that the Solow growth model is not a story of development because it has the apparent inability to account for observed differences in growth rates across countries and it possesses the counterfactual prediction that international trade should lead to rapid movement toward equality in capital-labor ratios and factor prices. The Solow growth model cannot be used therefore to explain persistent differences in growth rates. Despite these drawbacks he believes that growth theory offers the potential to explain variations in development across different countries. Indeed he remarks "technology...is the one factor isolated by the neo-classical model that has the potential to account for wide differences in income levels and growth rates." The hypothesis he puts forward is that by incorporating human capital as a proxy for the utilization of knowledge this will lead to a story of endogenous growth.

4.2 *Human Capital Models and Growth*

The human capital approach can be married with growth theory to incorporate the externality effects of education. This is what Romer (1986), Lucas (1988) and recently van Marrewijk et al. (1992) and Aghion and Howitt (1992) set out to achieve and a simple application of their approach is used subsequently¹⁰. Romer considers an economy in which knowledge is produced with a diminishing returns technology. New knowledge generates a positive externality through copy-cat or learning-by-doing effects. Consumption goods are produced as a function of the stock of knowledge and of other inputs. The crucial assumption is that the stock of knowledge in the production function for consumption goods exhibits increasing returns. Romer introduces the distinction between private and social factors of production, where private refers to labor input and social may be some average measure of labor quality at an economy wide level. Within this framework he shows that per capita output can grow without bound, that the rate of investment and the rate of return to capital may increase (rather than decrease) with an increasing capital stock, and the level of per capita output does not necessarily converge across countries. This paper represented one of the first major contributions linking development with growth.

Lucas develops the Solow growth model by incorporating human capital. Within this framework a model with homogeneous workers is considered. A worker is assumed to choose what fraction of time to devote to current production, with the remainder being allocated to human capital accumulation. The worker has a skill type which can be enhanced by the accumulation of human capital. Thus total output becomes a function of the level of the capital stock, the number of workers and the quality of workers. The important feature of the model is the distinction between internal and external effects of human capital accumulation. The internal effect of human capital is the direct effect the acquisition of knowledge has on productivity. The external effect is the indirect effect of human capital accumulation modelled as flowing from the average level of skill in the economy.

In fact two external effects are present. A higher average level of skill raises the level of individual productivity associated with a given amount of time invested in human capital. And a constant flow of investment in human capital leads to a situation in which the average skill level is constantly increasing (despite the fact that human capital is continuously being lost through death). This then leads to an intertemporal externality. The investment of one generation benefits future generations.

¹⁰ Similar approaches were first put forward by Arrow (1962) and Uzawa (1965).

The study by Aghion and Howitt looks at the implications of a situation in which economic growth is achieved through research-induced innovation. The prospect of future innovation reduces the quasi-rents available to any current innovation, and the implications of future research expenditure for current research expenditure are studied. This is probably only of limited relevance to developing countries.

On the other hand van Marrewijk, de Vries and Withagen look at a situation in which there are three inputs into production, capital, labor and human capital. Their analysis differs from that of Lucas in that human capital is seen as a third factor of production instead of interacting to enhance the effective labor supply. Recently-published work by Mankiw, Romer and Weil (1992) lends empirical support to this view, and appears to contradict the idea that there may be increasing returns associated with either capital accumulation or with education. The model underlying their empirical work, which was discussed in section 2, is one in which there are three factors of production, labor, human capital and physical capital; Mankiw, Romer and Weil estimate a Cobb-Douglas production function with these three factors present and can accept the hypothesis that the coefficients sum to 1, although they do not investigate the possibility of non-linear effects from their human capital variable; the implication of this is that they reject Lucas' hypothesis that the returns to education are higher in a society with a high average level of education. As noted in section 2, they use school attendance as a proxy for human capital, but acknowledge that they are unsure whether school attendance represents the level of human capital, or whether it represents the gross addition to a stock which would otherwise depreciate. The latter interpretation is consistent with the intertemporal externality identified by Lucas' model, and it is that aspect which we investigate subsequently.

Where does this take us with respect to education and development? First the model is capable of explaining differences in growth rates across countries like those described in section 2. Differences are explained by differences in human capital arising from differences in education. From a policy perspective this suggests that if developing economies are to catch up with more successful economies, it becomes necessary to take action to raise the rate of investment in human and physical capital above that which would be done if investment decisions were left to the private sector.

4.3 *Overlapping Generations Models and Growth*

The intertemporal externality naturally finds expression through the overlapping generations framework used in the model of section 3. This offers a way of describing how the stock of knowledge may be passed on from one generation to the next even if it decays somewhat in the

process. Before inserting this effect into the simulation model, a brief account of some of the other work of this type is offered.

Azariadis and Drazen (1990) construct a model that results in a multiplicity of locally stable balanced growth paths. In their model they introduce technological externalities featuring a threshold property. Thus for certain state variables like the quality of labor measured by literacy rates, when they reach a critical value then the externality impact becomes large.¹¹ In other words for increases in growth to take place it is necessary for an economy to reach a threshold level in labor quality, which means that education will play an important role in development.

The one sector approach of Diamond (1965) is used; population is constant; there is no national debt and no technical progress. As with Diamond a multiplicity of steady-states is shown to exist and it is argued that variations in social inputs (for example human capital) can affect the steady state. The model has a stronger microeconomic foundation than the Lucas framework. Within it agents choose the level of training that maximizes their utility, knowing that training when young improves productivity when old. They show that when individual yields to human capital investment rise with the average quality of labor, then there exist a multiplicity of balanced growth paths.

Becker, Murphy and Tamura (1990) come to similar conclusions. They present a model in which fertility is endogenous, being chosen as described in the model set out in section 3 with households maximizing a dynastic utility function. Households choose the level of expenditure on education so as to maximize their welfare through the effects of education on their offspring's income. The return to education is assumed to be low for small levels of education and then to rise for increasing amounts of education before falling off again for very high levels. This means that when human capital is scarce, the return to investing in human capital is low compared to the effect of investing in children. There are in fact two steady states to the model, one with high fertility, little education and a small capital stock, and the other with low fertility, a large capital stock and a high level of education. However, this result is crucially dependent on the structure of the function describing the return to education. Of the externalities described by Lucas, the results of Mankiw, Romer and Weil (1992) suggest one can reject the spatial externality. But the intertemporal externality cannot be so controversial. No one doubts that knowledge is passed on

¹¹Bowman and Anderson (1963) formalised the threshold argument in this context, using 1950s data to suggest that a literacy rate of between 30 and 40 percent is a precondition for take-off in growth. Easterlin (1981) discusses the role of primary education in economic take-off from a historical perspective. In fact the average developing country, with over 90% of the relevant age group now receiving primary education, ought to have crossed the sort of threshold which Easterlin identifies.

from one generation to the next. Once a technique has been invented it does not normally have to be reinvented. The model of section 3 is therefore extended while retaining the simple log-linear relationship between education and earning power.

4.4 *Simulation with Endogenous Growth*

We can model the growth in aggregate productivity by means of the relationship¹²

$$W_i = \Delta' W_{i-1} + v b_{i-1}' W_{i-1} \quad (24)$$

where b_{i-1}' is the duration of schooling determined by equation (23) and Δ' is the rate at which human capital decays. The model implies a rate of growth of labor productivity of

$$g_i = \Delta' - 1 + v b_{i-1}' \quad (25)$$

The population is assumed to be large, so that, by means of education, families can choose their own income relative to the labor productivity variable. However, each family cannot have a perceptible impact on the rate of growth. This means that the first order conditions for solving the model are unchanged. The only difference is that the rate of growth, instead of being exogenous, is described by equation (25). For simulation purposes, the coefficient on the duration of education, v , is assumed to be 0.032, corresponding to the value derived by Weale (1992) which appears to be perfectly consistent with Barro's results. The equation is normalized so that, in the hypothetical case of zero education, growth of 1% p.a. would still be possible¹³.

The simulation properties are summarized in figure 3. The first panel is simply a plot of equation (25), showing the link between education and growth. Secondly, the link between fertility and economic growth is plotted. The mechanism is straightforward. High education leads to faster growth but, at the same time, it raises the cost of children and so leads to a reduction in the rate of fertility. The results suggest an elasticity of fertility to growth in *per capita* GDP of around 3. The third panel combines the other two, presenting the relation between fertility and education once the effects of endogenous growth are taken into account.

¹²Such an expression is consistent with a situation in which human capital and labor enter into the production function multiplicatively. Mankiw, Romer and Weil (1992) suggest that the evidence is consistent with this.

¹³The mechanism is not discussed. This growth can be thought of as arising from catch-up with the advanced countries.

These results are broadly compatible with Barro's findings. A decline in the fertility rate from 2.5% to 0.2% is associated with an extension of education of 0.21, or 5.2 years. With a 10-year schooling program this is approximately equivalent to an increase in the proportion of the school-age cohort attending school of 0.52. Converting the simulated figures from rates of fertility to numbers of children per adult, the decline in fertility is from 1.85 to 10.5 children. Doubling these indicates the change in the number of children per woman. The fall in number of children per woman is 1.6 associated with an increase in participation at both types of school of 0.52. Barro's results imply, adding together the coefficients for primary and secondary school attendance, that this would reduce the number of children per woman by 2.4, not very different from the simulation figure of 1.6. This suggests that the simulation exercise is reasonably consistent with the facts. In particular it lends support to the idea that fertility is, at least in part, an economic decision and therefore that fertility is likely to be affected by any change, such as the availability of education, which alters the cost of having children.

5. Conclusions: The External Benefits of Education in Developing Countries

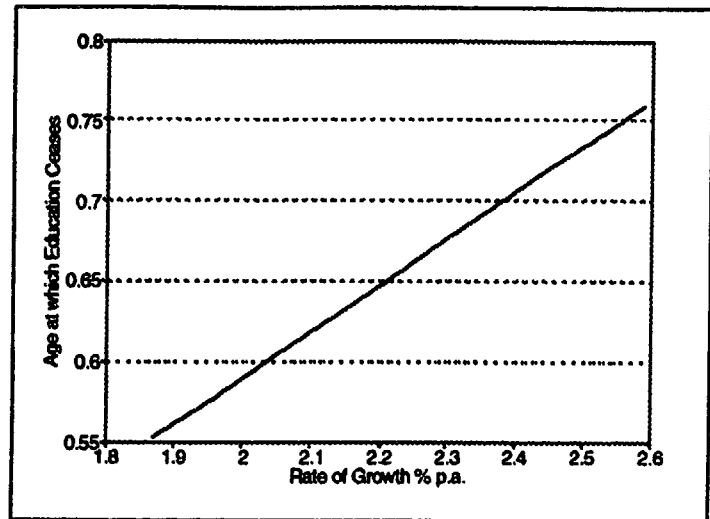
There is a reasonable amount of evidence for three types of externality arising from higher education. First of all, education seems to be associated with an improvement in public health. In developing countries the evidence relates to infant mortality, but other effects, which have been identified in developed countries, may also be present.

Secondly, there is ample evidence for a link between education and fertility in developing countries. This can be explained in economic terms by the idea that education raises the effective labor time parents have to devote to looking after their children, because it deprives them of the availability of child labor. Microeconomic studies indeed identify links between fertility, education and child wages but the elasticities are generally lower than those found by cross-country comparisons of fertility rates. Whatever one's view on the desirability of lower fertility, a reduction in fertility should be seen as a consequence of the widening of the availability of education.

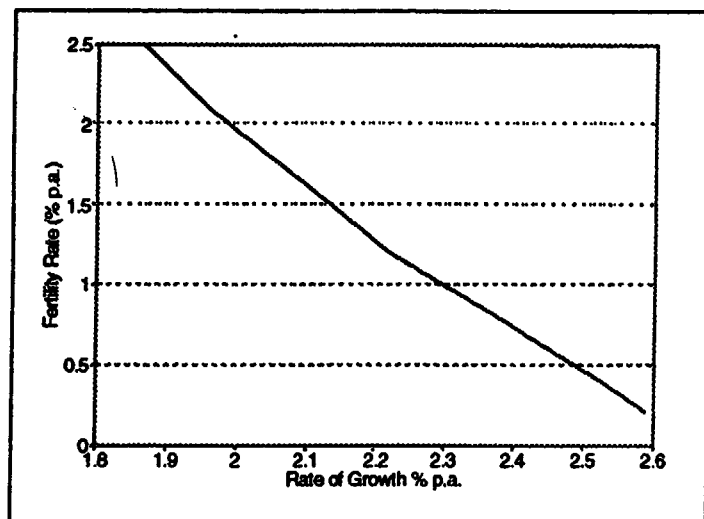
Thirdly, it is also suggested that there is a link between education and 'endogenous' growth or technical progress. This is harder to determine because a rising level of educational attainment leads to output growth even in the absence of such an externality. However, crude calculations performed in this paper suggest that the observed link between school enrolment and economic growth is roughly twice what would be expected to accrue simply from the rising level of attainment. These figures are, however, based on the assumption that education raises earning power by between 5% and 8% p.a. Many of the estimates of the return to education in developing countries are higher than this and, if such figures are accepted the gap between these and the results of cross-country comparisons to be bridged by such an externality is much reduced.

Figure 3 The Duration of Education, the Rate of Growth and the Fertility Rate

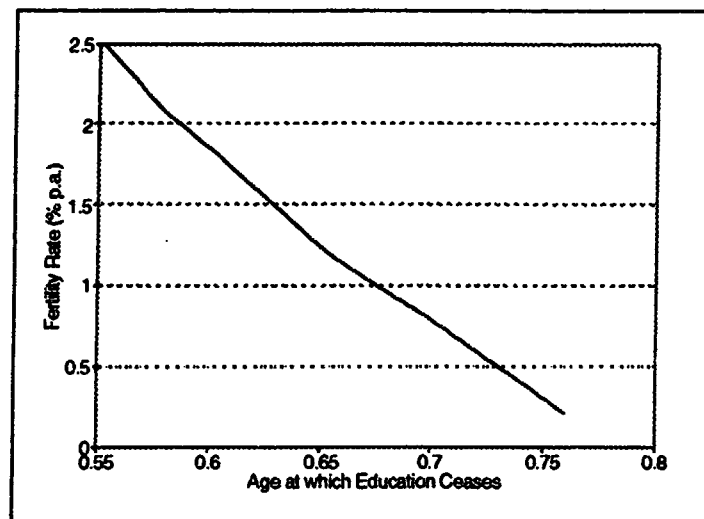
i) The Fraction of 'Youth' spent in Education and the Rate of *per Capita* Growth



ii) Fertility and Growth in Output *per Capita*



iii) The Fertility Rate and the Fraction of 'Youth' spent in Education



The fertility and technical progress effects should be regarded as closely interrelated. A simulation model has been set up in which fertility is modelled as an economic decision; the fertility rate is found to be positively related to the difference between the rate of interest and the return to education. When the rate of technical progress is made dependent on the cumulation of human capital, it is found that rapid *per capita* economic growth is associated with slow fertility and *vice versa*. Moreover the magnitudes which emerge from the model are broadly compatible with those found empirically. The simulation model therefore sheds insight on why these empirical interrelationships may be observed.

The fertility effects must be dependent on broadly-based education rather than the focusing of high-quality education onto an elite. But it is very difficult to say whether the growth effect arises from breadth or depth (which in itself can be either longer education or better quality education). The macroeconomic analyses do not distinguish the two, although it ought to be possible to test whether secondary education has an equal or higher effect on growth than does primary education. This would be an argument for depth. On the other hand a non-linear (increasing) effect on growth arising from a particular type of education might be an indicator of the importance of widening rather than deepening. Of course an assessment of the costs as well as the benefits is likely to tip the argument towards the provision of a wide level of basic education in the first instance. Technical progress is no use unless people are able to make use of it. But this does not answer the point because different levels of knowledge need different levels of skill for their exploitation.

The conclusions of this survey may then be summarized succinctly. Education leads to a fertility externality and to a growth externality. More research is needed to determine the structure of the growth externality and the presence of any increasing returns to education. But the presence of both externalities is documented well enough for them to be taken into account in cost-benefit analyses.

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APPENDIX**Population Dynamics and Economic Growth**

This appendix demonstrates how an increase in the fraction of the population undergoing secondary education will lead to faster growth of GDP *per capita* without there being any externality of the type described by Lucas (1988) present.

The following assumptions are made. First of all it is assumed that population is growth steadily at 2.05% p.a., the mean rate identified by Barro (1991). Secondly it is assumed that, up to the age of 4, the death rate is 87 per 1000, the rate identified by Barro. Beyond the age of 4 it is assumed that the probability of dying is given by the Gompertz function, $e^{0.1^{x-7}}$ with the choice of parameters being dictated by the need to ensure a reasonable expectation of life (57 years) and at the same time to yield, in combination with the population growth rate, a population with half the population under the age of 28. These stylized facts are probably broadly consistent with a notional developing country although there are some where the median age is as low as 18.

In 1950 the average fraction of the population of secondary-school age undergoing secondary education was 0.1. By 1960 this had risen to 0.23 and in 1985 it was 0.53, with the rate of increase of the fraction being close to 0.012 *per annum*.

If we assume that in the years before 1950 the fraction of the relevant age group attending secondary school was also 0.1, it is then possible to calculate the fraction of the workforce (aged 17-65) with secondary-school education. The fact that there are always more young people than old people means that it rises quite quickly in line with the school throughput, from 0.13 in 1960 to 0.34 in 1985. With a five-year secondary-school course, the average attainment level of the workforce has risen by 1.08 full years between 1960 and 1985. Denison's rule of thumb suggests that, as a consequence wages will have risen by 5-8% in real terms. If wages comprise 75% of the product, then GDP will be 4-6% higher than in a country where secondary-school attendance has remained at 0.1 of the relevant age group throughout. The effect on the growth rate will be $0.04/25$ to $0.06/25 = 0.0016$ to 0.0024 p.a. and this has been bought by an increase in the fraction attending secondary school of 0.13 in 1965. It suggests that the coefficient of the fraction taking secondary education should be $0.0016/0.13$ to $0.0024/0.13 = 0.012$ to 0.018 if there is no externality present. The lower limit is only just over 1 standard deviation below the figure which Barro quotes in the regression from which fertility is excluded.

These calculations suggest that Barro's results are likely to be consistent with the hypothesis of no externality from education, but it is also true that the population effects only explain about half of Barro's coefficients. One might therefore argue that about half of the effect

of education identified by Barro is an externality, and this figure is fairly close to the result identified by Weale (1992) from attainment data for the developed countries. Obviously the precision of the calculations could be improved by use of actual life tables which reflect the increase in the life expectancy of the population during the period instead of the hypothetical life table described here. There can be no doubt that stock adjustment effects have to be unravelled before clear evidence for an externality can be identified.

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